



## Integrating Renewable Energy Solutions through Collaborative Research: A Pathway to Sustainable Urban Development

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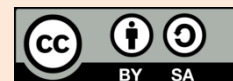
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### ABSTRACT

The rapid pace of global urbanization has intensified the demand for sustainable energy solutions, prompting the integration of renewable energy into urban development plans. This paper explores the critical role of collaborative research in overcoming the challenges associated with transitioning to renewable energy in urban areas, focusing on the contributions of bibliometric analysis. This study uses a bibliometric approach to analyze global research trends, key publications, and influential authors in renewable energy and urban planning. The analysis highlights the growing body of literature, revealing significant clusters of research activity centered around sustainable development, urban planning, and renewable energy technologies. Case studies of cities like Freiburg and San Francisco, which have successfully integrated renewable energy technologies, demonstrate how collaborative approaches can lead to more resilient and sustainable urban environments. Despite significant progress, challenges such as infrastructural investments, retrofitting complexities, and regulatory hurdles remain. The paper emphasizes the importance of continued collaborative research to address these barriers and ensure that the benefits of renewable energy are equitably distributed among urban populations. In addition, the study underscores the necessity of interdisciplinary collaboration and public engagement in fostering broader adoption and support of renewable energy technologies. The findings advocate for strengthened partnerships and continued innovation, supported by bibliometric insights, to facilitate the global transition towards sustainable urban energy systems. This research provides a comprehensive understanding of the evolving landscape of renewable energy research and its critical role in shaping sustainable urban development.

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## 1. INTRODUCTION

Rapid global urbanization in recent decades has placed significant pressure on urban infrastructure, energy systems, and the environment. United Nations data shows that more than 56% of the world's population currently lives in urban areas, and this proportion is projected to increase to around 68% by 2050. Urban areas account for more than 70% of global energy consumption and nearly 75% of greenhouse gas emissions, making cities a major contributor to climate change and environmental degradation. As urban populations continue to grow, increasing energy demands further exacerbate environmental pressures, underscoring the urgency of implementing sustainable urban development strategies that integrate environmental, economic, and social dimensions [1]. In this context, the adoption of renewable energy solutions is one of the main approaches to reducing the urban carbon footprint, increasing energy security, and strengthening the resilience of cities to environmental challenges [2].

Renewable energy technologies, such as solar, wind, hydro, and biomass, are gaining attention as sustainable alternatives to fossil fuels. In addition to being environmentally friendly, these technologies are also becoming more cost-competitive. However, the integration of renewable energy into urban energy systems still faces various obstacles, including technical challenges in grid integration, the need for large initial investments, and regulatory and policy complexities [3]. Therefore, the transition to renewable energy cannot rely solely on technological innovation but requires collaborative efforts involving various stakeholders. Collaborative research and innovation are key elements in accelerating the development and implementation of renewable energy solutions in urban environments [4].

The role of collaboration in advancing renewable energy solutions cannot be overstated. Collaborative research brings together stakeholders from academia, industry, government, and civil society, fostering innovation and enabling the co-creation of context-specific and scalable solutions [5]. This multi-stakeholder approach is particularly crucial in urban settings, where the complexity of energy systems and the diversity of urban landscapes demand tailored solutions. Through collaboration, cities can leverage the expertise of various actors to design and implement energy systems that are efficient but also equitable and inclusive [6].

Urban development and energy planning have traditionally been siloed, with limited integration between sectors and stakeholders. However, the growing emphasis on sustainability has led to a paradigm shift, where integrated approaches to urban planning and energy management are increasingly being adopted [7]. The concept of sustainable urban development emphasizes the need for cities to evolve to meet the needs of present and future generations without compromising the planet's ecological balance [8]. Renewable energy integration is a critical component of this vision, offering cities a pathway to achieving energy security, reducing environmental impact, and enhancing the quality of life for urban residents [9].

Several cities around the world have already embarked on the journey of integrating renewable energy into their urban systems through collaborative research initiatives. For instance, the city of Freiburg in Germany is often cited as a model of sustainable urban development, with its extensive use of solar energy and energy-efficient buildings supported by collaborative research between the city government, local universities, and private sector partners [10]. Similarly, San Francisco has implemented ambitious renewable energy programs in the United States driven by partnerships between municipal authorities, research institutions, and non-governmental organizations [11]. These examples demonstrate the potential of collaborative efforts in driving the transition to sustainable urban energy systems.

Despite the progress made, significant challenges remain in scaling up the integration of renewable energy in urban areas. These challenges include the need for substantial investments in infrastructure, the complexity of retrofitting existing urban environments, and the regulatory and policy hurdles that can impede the deployment of renewable energy technologies [2]. Addressing these challenges requires a concerted effort from all stakeholders, with collaborative research playing a pivotal role in identifying innovative solutions and best practices that can be replicated across different urban contexts [12].

In addition to technological and policy-related challenges, social acceptance of renewable energy solutions is also a critical factor in their successful implementation. Public awareness and engagement are essential in fostering a supportive environment for adopting renewable energy technologies. Collaborative research that includes community stakeholders can help to address concerns, build trust, and ensure that the benefits of renewable energy are equitably distributed among all urban residents [13]. This inclusive approach ensures that the transition to renewable energy contributes to broader social equity and justice goals.

Despite the increasing number of studies on renewable energy integration and sustainable urban development, most existing research remains focused on isolated dimensions, such as technological solutions, policy frameworks, or individual urban case studies, without providing a comprehensive view of how collaborative research in this field has developed globally. While technical and planning-oriented studies have contributed valuable insights into improving energy efficiency and optimizing urban energy systems, and policy-focused research has highlighted the importance of governance and regulatory support, these

contributions are often fragmented and context-specific. Similarly, case-based studies demonstrate that collaboration among governments, industry, and communities can effectively support renewable energy deployment, yet their findings are difficult to generalize beyond specific settings. As a result, there is still limited understanding of global research trends, collaboration patterns, and thematic evolution in collaborative renewable energy research within urban contexts. To address this gap, this study employs a bibliometric approach to systematically analyze the global scientific literature, identify influential publications and key contributors, map collaboration networks, and explore emerging research themes, thereby offering a holistic perspective that can support future research directions and inform policy development for sustainable urban energy transitions.

## 2. METHOD

This study employs bibliometric analysis to systematically review the scientific literature related to sustainable development. The bibliometric approach was chosen because it provides a quantitative and structured overview of developments in a field of research, particularly in mapping publication trends, patterns of collaboration between researchers and institutions, and the development of research themes over time. This method is considered relevant to the research objectives, which focus on understanding the research landscape and collaborative dynamics that are not easily obtained through conventional literature reviews. The analysis was conducted using the Biblioshiny application, a web-based interface of the bibliometrix package in R software, which supports various bibliometric analyses and visualizations. The research process was carried out in stages, including data collection from selected scientific databases, data preprocessing to ensure consistency and accuracy, and a series of analyses to identify publication trends, writing patterns, collaboration networks, and the evolution of research themes. To clarify the research flow, these methodological stages are presented in a flowchart in the methods section.

### 2.1 Data Retrieval and Search Strategy

The initial step involved systematically collecting relevant scholarly publications from Scopus. It covers publications up to July 2024. Data retrieval in bibliometric analysis refers to the process of collecting and extracting relevant data from various scientific databases and repositories for the purpose of analyzing scientific literature. This step is crucial for performing any bibliometric analysis as it forms the foundation upon which further analysis is built. The goal is to gather publications, citations, and metadata (such as authors, affiliations, keywords, etc.) to understand the structure and impact of research within a specific field or topic. Data retrieval is critical because incomplete or inaccurate data can significantly skew the results of bibliometric analyses, leading to incorrect conclusions about the trends, impact, and relationships within a research domain. There are some key elements of data retrieval in bibliometric analysis include:

1. Selection of Databases. Choosing appropriate databases such as Scopus, Web of Science, Google Scholar, or PubMed, which offer a wide range of peer-reviewed articles, conference papers, and other scholarly outputs.
2. Search Strategy. Defining a clear and effective search query using keywords, phrases, and Boolean operators to ensure comprehensive coverage of the research field being studied.
3. Filtering Data. Applying filters based on time range, subject area, document type, or language to narrow down the search results to the most relevant studies.
4. Downloading Data. Exporting data from these databases in a format that can be used for bibliometric tools (e.g., BibTeX, CSV, RIS).
5. Quality Control: Ensuring the accuracy and completeness of the retrieved data, removing duplicates, and verifying the validity of the records before proceeding to analysis.

In bibliometric analysis, the search strategy refers to a systematic approach used to identify, collect, and select relevant literature from various databases. The goal of the search strategy is to ensure that the data gathered is comprehensive and relevant to the specific research question or field of study. A well-designed search strategy is crucial for obtaining high-quality data that accurately reflects the trends, networks, and impact of publications in the chosen research domain, include:

1. Keywords Identification. A set of relevant keywords and phrases related to sustainable development were identified through a preliminary literature review and expert consultation.
2. Search Query Construction. The keywords were combined using Boolean operators to construct a comprehensive search query. In this article, the query is:  
(TITLE-ABS-KEY ("renewable energy" OR "sustainable energy" OR "clean energy" OR "green energy") AND TITLE-ABS-KEY ("collaborative research" OR "collaboration" OR "partnership" OR "joint research" OR "cooperation")) AND TITLE-ABS-KEY ("urban development" OR "sustainable cities" OR

"urban sustainability" OR "urban planning") AND (TITLE-ABS-KEY ("innovation" OR "technology" OR "solution" OR "implementation")))

3. Inclusion and Exclusion Criteria. Articles were included if they were peer-reviewed, written in English, and directly related to the research topic. Conference papers, book chapters, and grey literature were excluded to maintain consistency and quality.
4. Time Frame. The search encompassed publications from 1995 to 2024, allowing for an analysis of temporal trends.

## 2.2 Data Exportation, Data Preprocessing and Step Involved

The retrieved records were exported in CSV compatible with Biblioshiny, ensuring that all necessary bibliographic information (e.g., authors, titles, abstracts, keywords, citations) was adequately captured. Before analysis, the dataset underwent a meticulous preprocessing phase to ensure the accuracy and reliability of the results. Several steps involved in this analysis, include:

1. Data Cleaning. Duplicate records were identified and removed. Inconsistencies in author names and affiliations were standardized using automated and manual procedures.
2. Keyword Unification. Synonymous and variant forms of keywords were harmonized to prevent fragmentation in thematic analyses.
3. Handling Missing Data. Entries with significant missing information were reviewed, and where possible, missing data were supplemented through cross-referencing other databases or excluded if data were insufficient.
4. Normalization. Citation counts were normalized to account for variations in publication years, facilitating fair comparisons across different periods.

## 2.3 Bibliometric Analysis and Visualization Techniques

The cleaned and standardized dataset was subjected to various bibliometric analyses using the functionalities provided by Biblioshiny. It includes descriptive analysis, citation analysis, collaboration analysis, and thematic analysis. In this analysis, several relevant software were used, including:

1. Biblioshiny for bibliometric. It provides an interactive and user-friendly platform for conducting and visualizing bibliometric analyses.
2. R Statistical Software. Used as the underlying framework for executing complex analyses and generating reproducible results.
3. Additional Packages. It utilized supplementary R packages such as ggplot2 for enhanced data visualization and graphs for advanced network analysis.

Biblioshiny offers robust visualization tools that were utilized to present the analytical results effectively:

1. Trend Plots. Graphical representations showing publication and citation trends over time.
2. Network Maps. Visualizations of co-authorship, co-citation, and co-word networks illustrate the scholarly community's relationships and structures.
3. Thematic Maps. Strategic diagrams plotting themes based on their centrality and density, categorizing them into motor, fundamental, niche, and emerging themes.
4. Tree Maps and Word Clouds. Visual displays highlight the prominence of specific journals, authors, or keywords.

## 2.4 Ethical Considerations and Limitations

Ethical considerations in bibliometric analysis ensure that research is conducted responsibly and ethically. The study adhered to ethical standards in data handling and reporting:

1. Data Privacy. It ensured confidentiality and proper use of author and institutional information, complying with data usage agreements of the source databases.
2. Reproducibility. It maintained transparency in methodological procedures, providing detailed descriptions to facilitate replication and verification by other researchers.
3. Acknowledgement of Sources. Appropriately cited all data sources and referenced works used throughout the analysis.

Bibliometric analysis is a powerful tool for evaluating research output, impact and trends within academic literature. While comprehensive, the study acknowledges certain limitations:

1. Database Coverage. Reliance on specific databases may exclude relevant literature indexed elsewhere, potentially affecting the completeness of the analysis.
2. Language and Publication Bias. Focusing on English-language and peer-reviewed publications might overlook significant contributions in other languages or formats.

Dynamic Nature of Data. Bibliometric data continually evolve; thus, findings represent a snapshot based on the data available up to the retrieval date.

### 3. RESULTS AND DISCUSSIONS

The optimization results using both PSO and GOA for PD, PI, and PID controllers were analyzed based on compressor power consumption and battery temperature control. The system was simulated in MATLAB/Simulink, and the performance was evaluated through convergence graphs, objective function values, and time-domain response.

Figure 1 presents a bibliometric summary of a research dataset covering a timespan from 1995 to 2024. It includes 159 documents sourced from 120 different outlets, with an annual growth rate of 12.93%. Four hundred ninety-six authors contributed to these publications, with 29 authors producing single-authored documents. The dataset shows a high level of collaboration, with 25.16% of the papers involving international co-authorship and an average of 3.35 co-authors per document. The analysis identified 552 unique author keywords, and the documents collectively reference 7,390 sources. The average age of the papers is 5.19 years, and each document has received an average of 15.24 citations, indicating the overall impact and relevance of the publications within the field.



Figure 1. Finding overview

Figure 2 shows a line graph illustrating the annual scientific production of articles from 1995 to 2024. The vertical axis represents the number of articles published yearly, while the horizontal axis spans the years. The data shows a relatively low and stable number of publications from 1995 until around 2010, with only slight fluctuations. However, beginning in the mid-2010s, there was a noticeable increase in scientific output, which became more pronounced from 2018 onwards. The most significant surge occurred in the last few years, particularly in 2023 and 2024, when the number of published articles sharply rose, reaching its peak in 2024. This trend suggests a growing interest and activity in the research domain over time, with a marked acceleration in recent years.

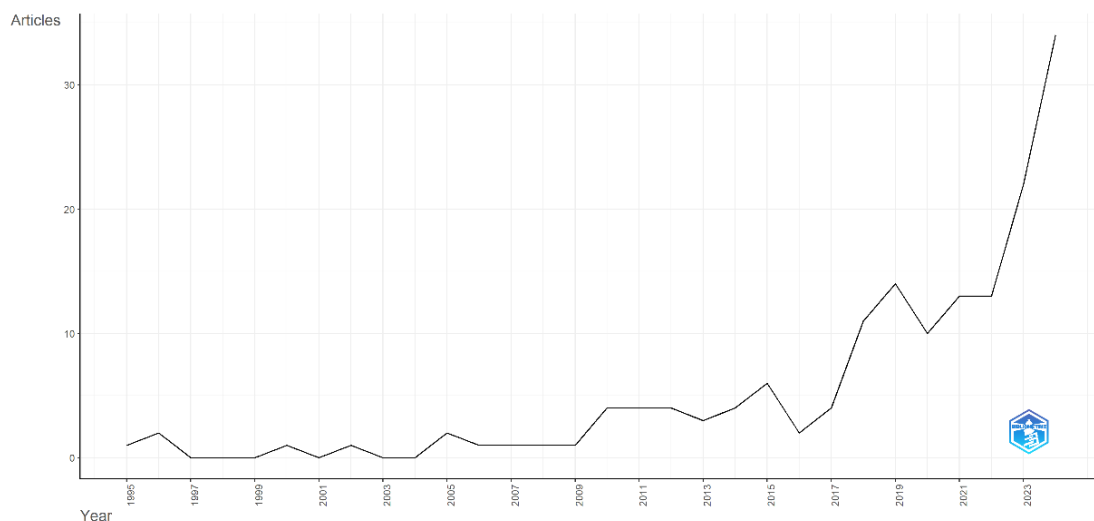


Figure 2. Annual scientific production

#### 3.1 Source Analysis

Figure 3 highlights the most relevant sources, such as journals and conference proceedings, based on the number of documents they have published in a specific research domain. The leading source is Sustainability (Switzerland), which has published eight papers, making it the most prominent publication outlet

for research in this field. The following is Energies, which has six papers and is significant in disseminating relevant research. Both IOP Conference Series: Earth and Environmental Science and IOP Conference Series: Materials Science and Engineering have each published four documents, indicating their importance in the academic community. Other notable sources include E3S Web of Conferences, Sustainable Cities and Society, VTT Tiedotteita - Valtion Teknillinen Tutkimuskeskus, and WIT Transactions on Ecology and the Environment, each contributing three documents. Lastly, AIP Conference Proceedings and Applied Energy have published two papers each, showing their involvement in the research area with fewer publications. This chart effectively identifies the key sources contributing to the research field, with "Sustainability (Switzerland)" being the most frequently utilized platform.

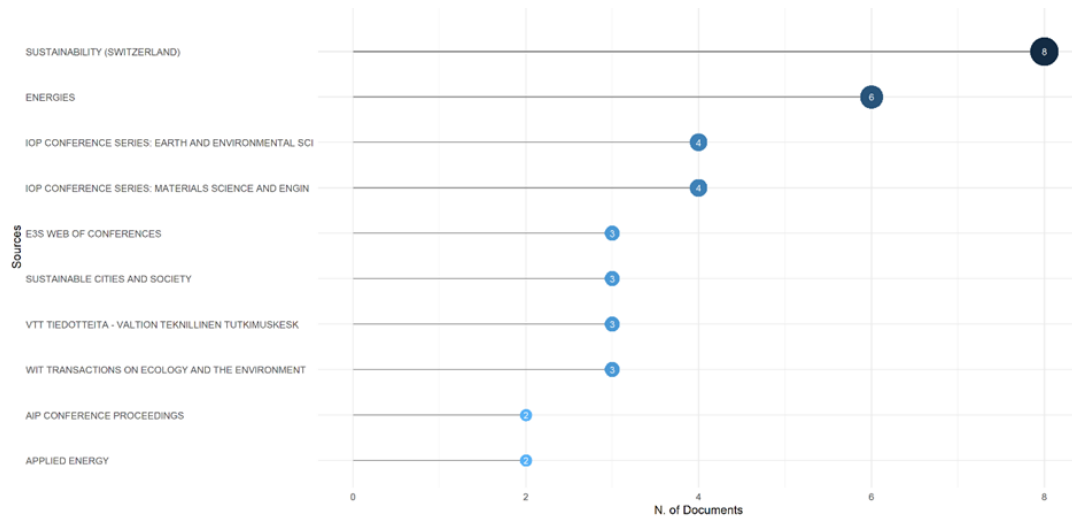


Figure 3. Most relevant sources

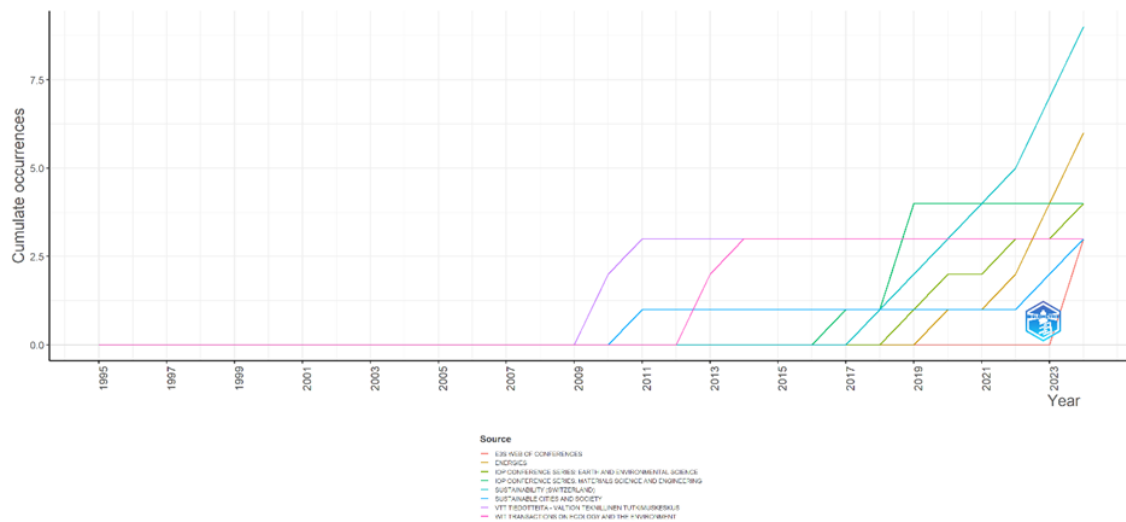


Figure 4. Sources production over time

Figure 4 illustrates the cumulative production of various academic sources (journals and conference proceedings) from 1995 to 2024. The vertical axis represents the cumulative occurrences, or the total number of documents published by each source up to a given year, while the horizontal axis tracks the years. Each colored line represents a different source, showing how their contributions have accumulated. Notably, Sustainability (Switzerland) has experienced the most significant growth in recent years, particularly after 2017, reaching the highest cumulative total. Other sources like Energies and IOP Conference Series: Earth and Environmental Science also show substantial increases in publication volume, particularly since 2015. The graph reveals that while some sources, like Sustainable Cities and Society and E3S Web of Conferences, have steadily contributed, others have seen more recent and rapid growth, reflecting the increasing focus on these

sources' research topics. This visualization effectively demonstrates the evolving contributions of different sources to the research field, highlighting trends in publication activity over the years.

### 3.2 Author Analysis

The bar chart in Figure 5 displays the most relevant authors in a specific research domain based on the number of published documents. Each author listed on the vertical axis has contributed exactly three papers, as indicated by the horizontal bars extending to the number 3 on the horizontal axis. The chart highlights that all the authors have shown—Dechnik M, Fedorczak-Cisak M, Furtak M, Kulhar KS, Lahti P, Nedungadi P, Nummelin J, Nystedt A, Raman R, and Sepponen M—have made equal contributions in terms of publication count. It suggests a relatively balanced distribution of research output among these critical contributors, with no single author dominating the number of publications within this dataset. The equal publication count indicates a collaborative or evenly spread authorship pattern within the research field.

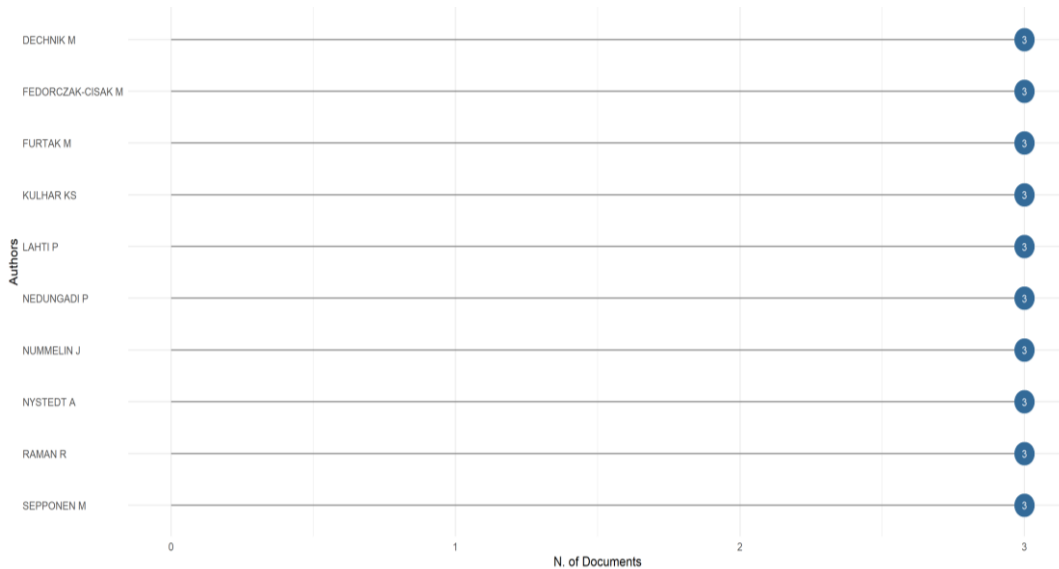


Figure 5. Most relevant authors

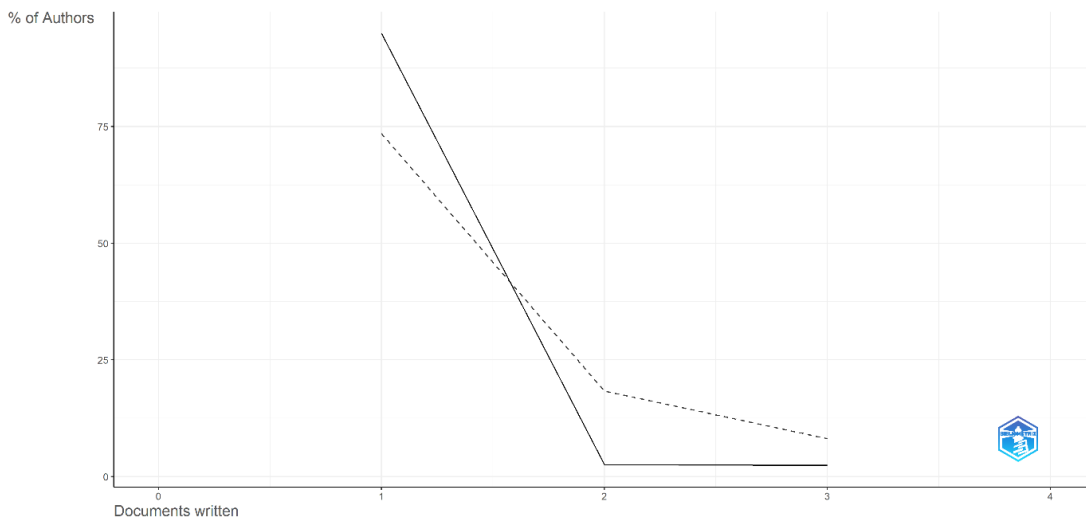


Figure 6. Author productivity through Lotka's law

Figure 6 illustrates author productivity in a specific research domain according to Lotka's Law, which suggests that only a tiny percentage of authors contribute many publications, while the majority contribute fewer. The horizontal axis represents the number of documents an author writes, while the vertical axis shows the percentage of authors who have contributed that number of records.

The solid line on the graph shows the actual distribution of author productivity within the dataset, while the dotted line likely represents the theoretical distribution predicted by Lotka's Law. The graph indicates

that many authors (over 75%) have written only one document, reflecting the typical distribution where most researchers contribute minimally. As the number of documents increases (moving right along the x-axis), the percentage of authors who have written that many documents sharply decrease, with very few authors contributing three or more documents. This pattern is consistent with Lotka's Law, where the productivity of authors diminishes exponentially with the increase in the number of publications. The graph effectively demonstrates the skewed nature of academic productivity, where a small number of highly prolific authors produce a large portion of the total research output.

Figure 7 highlights the most relevant academic affiliations regarding research output, explicitly focusing on the number of articles published by researchers associated with these institutions. The University of Cape Town stands out as the leading institution, with ten published articles, making it the most significant contributor to this dataset. Following closely, the University Institute of Technology of Douala has published eight articles, indicating its substantial role in advancing research in the field. Additionally, the University of the Basque Country (UPV/EHU) and Kabul University have also made notable contributions, with 7 and 6 articles showcasing their active engagement in the research domain.

Other institutions, such as the University of Twente and Tianjin University, have each published six articles, reflecting their essential roles in the academic community. Universitas Negeri Semarang follows with five articles, highlighting its involvement in the research field. Furthermore, the Amrita School of Business, Amrita School of Computing, and Architect and Urban Planning have each contributed four articles, marking them as relevant but slightly less prolific than the leading institutions. This chart illustrates a diverse range of academic institutions, including Africa, Europe, and Asia, actively contributing to the research landscape, with the University of Cape Town emerging as the most influential affiliation in this dataset.

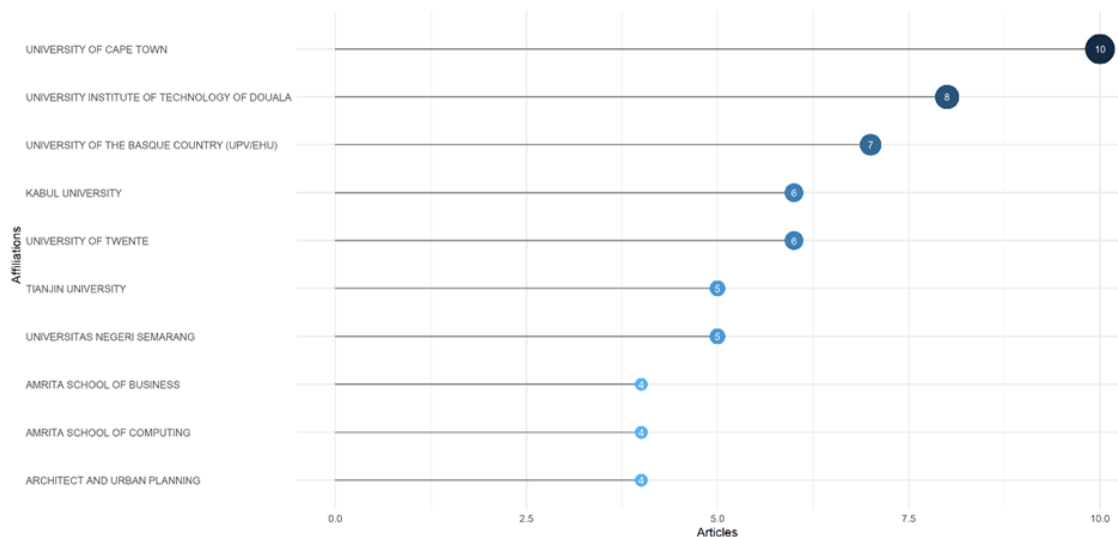


Figure 7. Most relevant affiliations

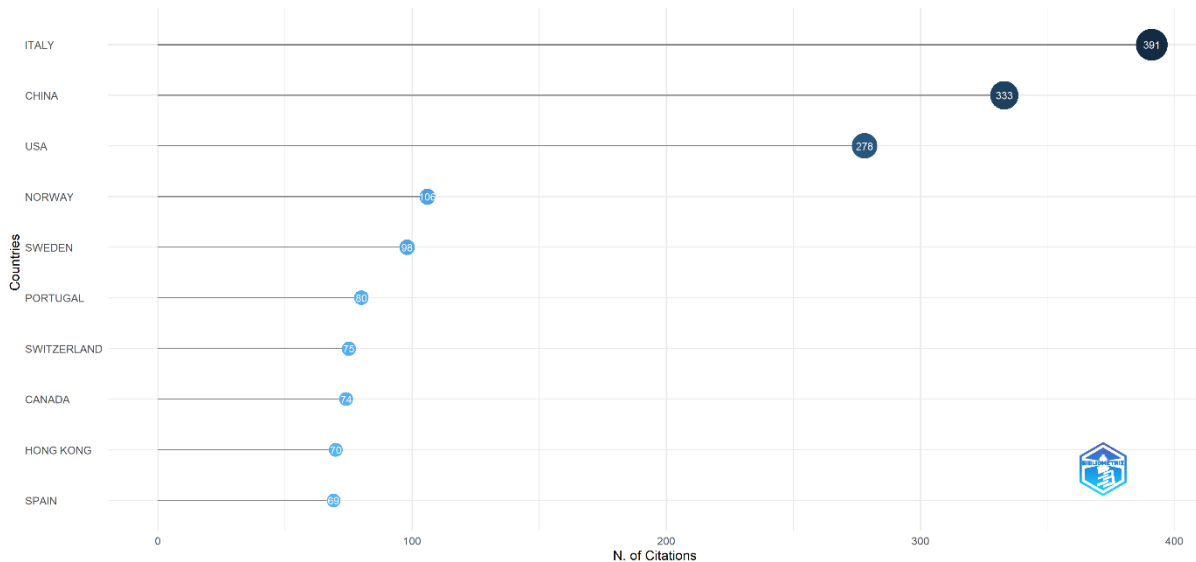


Figure 8. Most cited countries

Figure 8 illustrates the most cited countries in a specific research domain, ranked by the total number of citations their publications have received. The vertical axis lists the countries, while the horizontal axis shows the number of citations. Italy has the highest number of citations, totalling 391, indicating its strong influence and impact in the research field.

- China follows closely with 333 citations, showing significant research output and recognition.
- The USA is another major contributor, with 278 citations, highlighting its substantial role in the global research landscape.
- Norway and Sweden have received 106 and 98 citations, respectively, placing them among the more impactful countries in this dataset.
- Other countries like Portugal (80 citations), Switzerland (75 citations), Canada (74 citations), Hong Kong (70 citations), and Spain (69 citations) also feature prominently, though with a lower number of citations compared to the leading countries.

This chart effectively demonstrates the global distribution of research influence, with European countries like Italy, Norway, and Sweden, as well as major players like China and the USA, standing out for their high citation counts. The data suggests that research contributions from these countries are widely recognized and cited, underscoring their importance in the research domain.

### 3.3 Documents Analysis

Figure 9 highlights the most globally cited documents in a particular research domain, showcasing the influential works that have shaped the field. The document by Manfren M, 2011, published in *Applied Energy*, leads with 354 citations, marking it the most impactful study in this dataset. This high citation count reflects the significant contribution of this work to the academic community and its continued relevance over time. Close behind is Zhang F, 2020, in *Technological Forecasting and Social Change*, which has garnered 246 citations, demonstrating its substantial recognition in a relatively short period. Additionally, Alberti M, 1996, published in *Environmental Impact Assessment Review*, with 226 citations, illustrates the lasting impact of foundational research in the field.



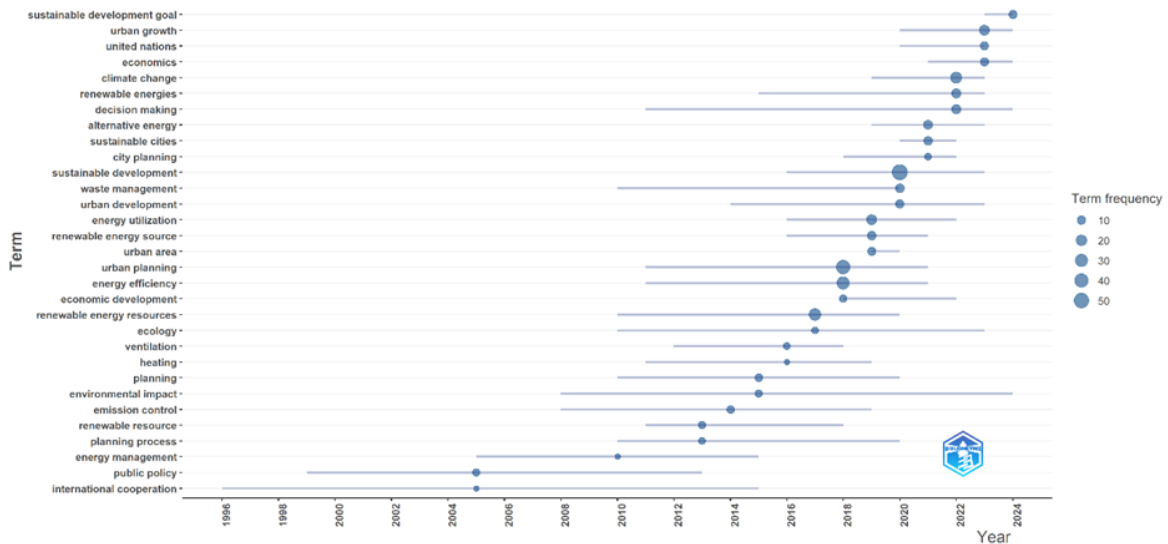


Figure 11. Trends topics

This visualization in Figure 11 displays the trend topics in a specific research domain over time, with the vertical axis listing various terms and the horizontal axis representing the years from 1996 to 2024. Each term's frequency of occurrence is depicted by the size of the circles, where larger circles indicate more frequent usage of the term in the literature. The horizontal bars next to each term show the period during which that term has been used, providing insights into when specific topics emerged and how they have evolved.

The chart reveals those topics such as "sustainable development goal" and "urban growth" have become increasingly prominent in recent years, particularly after 2015, reflecting the global focus on sustainable urbanization and the United Nations' Sustainable Development Goals (SDGs). Terms like "climate change", "renewable energies", and "energy efficiency" also show strong growth trends, indicating their centrality in discussions around environmental sustainability and energy management. The increasing frequency of these terms, particularly in the last decade, aligns with the heightened global awareness and policy initiatives to address climate change and promote renewable energy.

Other significant terms, such as "urban planning", "decision making", and "sustainable cities", have also seen steady growth, reflecting the interdisciplinary nature of urban studies and the need for integrated approaches to city planning and development. The emergence and consistent use of terms like "alternative energy", "renewable energy resources", and "energy utilization" further emphasize the ongoing shift towards more sustainable energy practices and the critical role of renewable energy in achieving sustainable development goals.

The chart also highlights earlier terms like "international cooperation", "public policy", and "environmental impact", which have been consistently relevant over time, though their frequency has fluctuated. It suggests that while these foundational concepts remain important, newer topics such as "sustainable development" and "urban growth" have taken center stage in recent years, reflecting evolving research priorities and global challenges.

Overall, this visualization provides a comprehensive overview of how research topics have developed over the years, illustrating the emergence of new focus areas and the sustained importance of established themes. The clear trend towards sustainability-related topics underscores the global shift towards addressing environmental and urban challenges through innovative and collaborative approaches. This trend analysis is valuable for researchers looking to identify key focus areas, understand the historical context of specific topics, and anticipate future research directions.

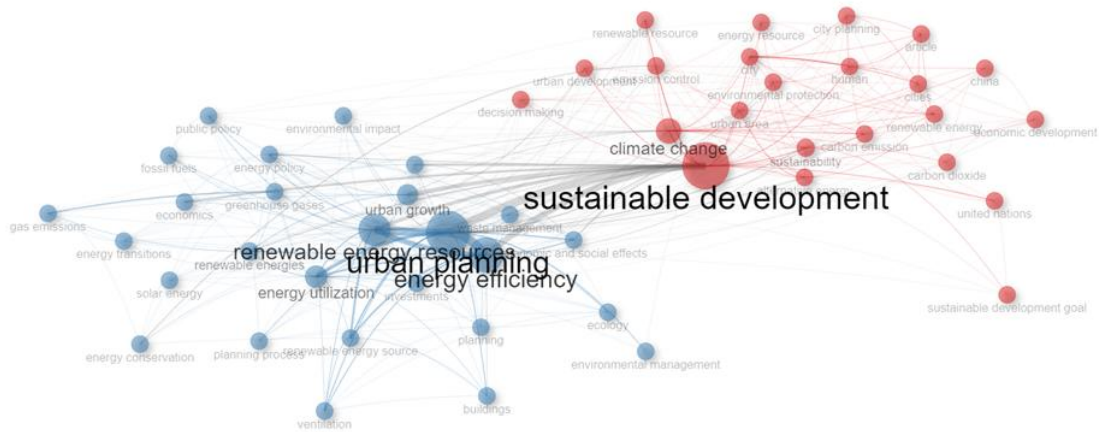


Figure 12. Co-occurrence network

Co-occurrence network in Figure 12 visualizes the relationships between key terms or keywords within a specific research domain, illustrating how frequently these terms appear together in the literature. The nodes represent different terms, and their size indicates the frequency of their occurrence—the larger the node, the more frequently the term appears. The lines (edges) connecting the nodes represent the co-occurrence relationships between terms, with the thickness of the lines indicating the strength of the connection—the thicker the line, the more often the terms appear together.

At the center of the network, "sustainable development" stands out as the most prominent term, connected to a wide range of other terms, highlighting its central role in the research domain. This term is closely associated with other significant themes such as "climate change," "urban planning," "energy efficiency," and "renewable energy resources." These connections suggest that sustainable development is a multidisciplinary concept that intersects with various fields, including urban planning, energy management, and environmental protection.

The network also shows clusters of related terms that are often discussed together. For example, the blue cluster includes terms like "urban planning," "energy efficiency," "renewable energy resources," and "urban growth," indicating a strong focus on sustainable urban development and energy efficiency. In contrast, the red cluster, which includes "climate change," "environmental protection," "carbon emission," and "sustainability," highlights the environmental aspects of sustainable development, particularly concerning climate change and carbon management.

The co-occurrence network effectively maps out the thematic structure of the research field, showing how different concepts are interconnected. It reveals that sustainable development is a central topic and ties together various subfields, from urban planning and energy efficiency to climate change and environmental management. This visualization helps researchers identify key areas of overlap, potential interdisciplinary collaborations, and emerging trends in the literature.

Figure 13 shows a co-citation network visualization that represents the relationships between different scholarly journals based on the frequency with which they are cited together in other works. In this network, each node represents a journal, and the node's size indicates the journal's prominence in the network, with larger nodes being more frequently co-cited. The lines, or edges, connecting the nodes represent the strength of the co-citation relationships, with thicker lines indicating a higher frequency of co-citations between the connected journals.

The network is divided into clusters, each represented by a different color, indicating groups of journals frequently co-cited together, suggesting that they cover similar or related topics. For example, the green cluster is centered around the journal "Sustainability," indicating that it is frequently co-cited with journals such as "Applied Energy" and "Renewable Energy." The blue cluster, which includes "Journal of Cleaner Production" and "Science of the Total Environment," suggests a focus on environmental and ecological research. The red and purple clusters highlight other specialized areas, such as energy policy and renewable energy. This network provides insight into the structure of academic literature, showing how different research areas are interconnected through the citation practices of scholars.

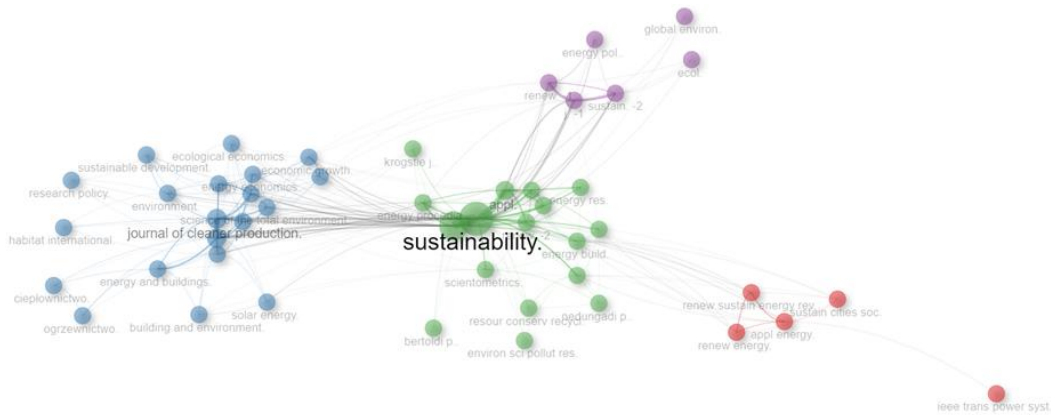


Figure 13, Co-citation network visualization

The thematic map in Figure 14 visually represents different research themes based on their degree of development (density) and relevance (centrality) within a particular field of study. The map is divided into four quadrants, each representing a different type of theme:

1. **Motor Themes (Upper Right Quadrant).** These themes are highly developed and central to the research field, indicating that they are well-established and play a critical role in the overall research landscape. In this map, terms like "climate change," "alternative energy," and "sustainability" fall into this category, suggesting that these topics are not only well-developed but also central to ongoing research discussions.
2. **Niche Themes (Upper Left Quadrant).** These themes are well-developed but have low centrality, meaning they are specialized topics that are less connected to the broader research field. In this map, no themes are explicitly positioned in this quadrant, indicating that the specialized topics in this field may not be as prominent or are more integrated with other themes.
3. **Emerging or Declining Themes (Lower Left Quadrant).** Themes in this quadrant have low development and low centrality, meaning they are either emerging areas of research that are not yet fully developed or declining areas of study that are becoming less relevant. The map shows "sustainable development," "urban growth," and "sustainable cities" in this quadrant, suggesting these topics might be in the early stages of development or perhaps losing prominence in the current research context.
4. **Basic Themes (Lower Right Quadrant).** These themes are central to the research field but are not as well-developed, indicating that while they are essential, they may require further research and development. The map places "urban planning," "energy efficiency," and "renewable energy resources" in this quadrant, highlighting them as critical areas that are central to the field but may need more in-depth exploration and development.



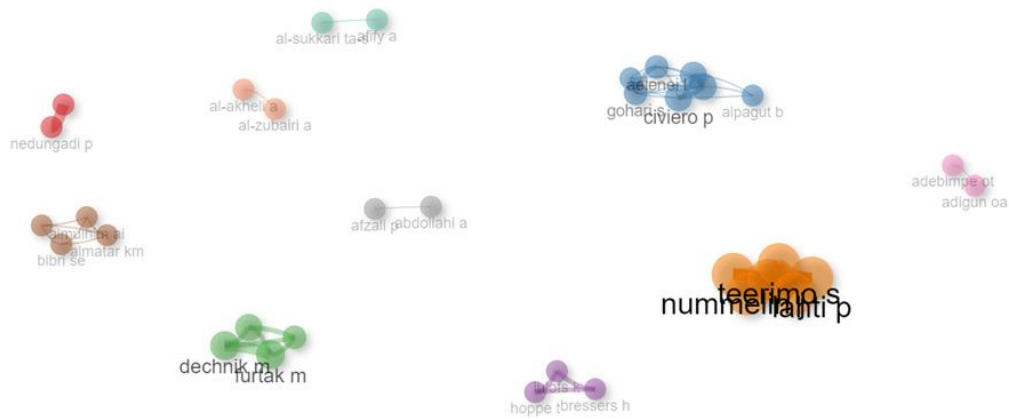


Figure 16. Collaboration network visualization

This collaboration network visualization in Figure 16 displays the relationships between authors based on their co-authorship in academic publications. Each node represents an author, with the node's size indicating the level of their contribution or prominence in the collaboration network. The lines connecting the nodes represent co-authorship links, with thicker lines indicating stronger or more frequent collaborations.

The network is organized into several clusters, each representing a group of authors who frequently collaborate. The largest and most prominent cluster is centered around "Nummelin J" and "Teerimo S," indicating that these authors are central figures in their collaborative network, working closely with several other researchers. Other clusters, such as those involving "Dechnik M" and "Furtak M" or "Civiero P" and "Gohari S," show smaller but still significant groups of authors who collaborate closely within their specific research areas. The scattered arrangement of the clusters suggests that while there are strong collaborations within certain groups, there is less interaction or co-authorship between these different clusters. It could indicate that these groups work on different subfields or specializations within the broader research domain. The presence of isolated pairs or small clusters, such as "Adebumpe OT" and "Adigun OA," or "Al-akheli A" and "Al-Zubair A," indicates focused collaborations between specific researchers, possibly within more niche or specialized areas of study. Overall, this network map provides insight into the structure of research collaborations, highlighting key authors, major collaborative groups, and the relative isolation or interconnectedness of different research teams.

Figure 17 is the world collaboration map that visualizes the global research collaborations between countries. Each country is represented on the map, with varying shades of blue indicating the intensity of cooperation and darker shades representing higher levels of research activity and collaboration. The lines connecting the countries signify collaborative efforts between researchers in different countries, with thicker lines indicating more frequent or stronger collaborative ties. The map shows significant collaboration activity between European countries, with several connections extending to North America (especially the United States) and Asia (particularly China and India). The United States, China, and several Western European countries appear as central hubs in the global research network, indicating that these nations are key players in international research collaborations. The connections suggest that these countries frequently collaborate, contributing to a robust and interconnected global research community. Overall, this map highlights the global nature of research, with collaborations crossing national borders, and it underscores the importance of international partnerships in advancing scientific knowledge.

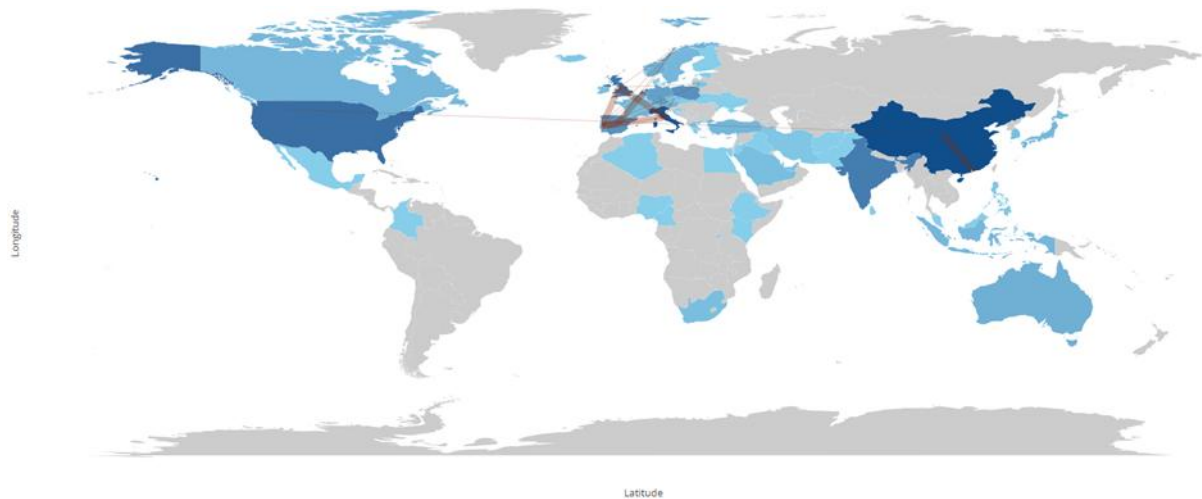


Figure 17. Countries collaboration world map

The analysis of publications on renewable energy and urban planning reveals a significant increase in research output over the past decade, reflecting the growing importance of sustainable development in academic discourse. The surge in publications is particularly evident after 2015, which coincides with the adopting of the Paris Agreement, an international treaty on climate change. This trend indicates a heightened global awareness and commitment to transitioning towards more sustainable energy practices. The research concentration in this area underscores its critical role in addressing climate change, urbanization challenges, and sustainable development goals (SDGs) [14].

Urban planning has emerged as a central theme in the literature, often intersecting with renewable energy discussions. This intersection highlights the necessity of integrating renewable energy solutions within urban planning frameworks to create resilient, sustainable cities. The growing body of work emphasizes incorporating renewable energy sources, such as solar and wind, into urban infrastructure. This integration is essential for reducing carbon footprints and enhancing the sustainability of urban environments [15]. The bibliometric analysis further shows that urban planning is increasingly viewed as a multidisciplinary field that must consider energy efficiency, environmental impact, and social equity.

The geographical distribution of research output reveals those countries like the United States, China, and Italy lead in publications on these topics. These countries' prominence in the research landscape is likely due to their substantial investments in renewable energy technologies and urban development projects. Moreover, the international collaborations identified in the bibliometric analysis suggest a global effort to address the shared challenges of sustainable development. Such collaborations are crucial for knowledge transfer and the implementation of best practices across different regions [16].

The analysis also highlights several critical influential authors and institutions in the field. For instance, authors affiliated with institutions such as the University of Cape Town and Universiti Teknologi Malaysia have contributed significantly to the discourse on renewable energy and urban planning. These institutions' focus on sustainable development research aligns with their regional and national priorities, particularly in areas facing severe environmental challenges. The clustering of these institutions in the bibliometric network further indicates their central role in advancing research and influencing policy on a global scale [17].

The thematic evolution of the research, as shown in the co-occurrence and thematic maps, suggests a shift from traditional energy topics to more integrated and complex discussions around sustainability. Early research focused heavily on technical aspects of renewable energy, but recent studies increasingly explore the broader social, economic, and environmental implications. This shift reflects the evolving understanding of sustainability, which now encompasses a holistic view that integrates energy, urban development, and social equity [18].

Although showing rapid progress, the results of this analysis also reveal a number of gaps that are consistent with the findings of previous bibliometric studies in the field of renewable energy and sustainability. The existing literature is still dominated by research that emphasizes technological aspects and technical solutions, while discussions on the policy framework, governance, and institutional support needed to encourage the widespread implementation of renewable energy are still relatively limited, especially in the context of developing countries. This condition shows that technological advances have not been fully accompanied by the strengthening of policy and institutional dimensions. In addition, the integration of renewable energy into established urban infrastructure still faces various challenges, both technical and

financial, especially in cities with high population densities. These findings indicate the need for more interdisciplinary research that not only examines engineering aspects but also considers urban planning and public policy perspectives [19].

Viewed from a broader context, the results of this study reinforce previous bibliometric literature findings that emphasize the importance of international collaboration and multidisciplinary approaches in addressing complex sustainability challenges. The identified collaboration patterns show that cross-border cooperation plays an important role in knowledge development and the exchange of best practices in the fields of renewable energy and sustainable urban development. However, several limitations of this study need to be noted. The analysis was based on publications indexed in specific scientific databases, so it is possible that relevant studies were not included, especially those published in local journals or in languages other than English. Furthermore, as is characteristic of bibliometric analysis in general, this study emphasizes quantitative patterns of publication, citation, and thematic relevance, without evaluating in depth the quality of content or practical impact of each study. Nevertheless, by placing the findings in the context of broader bibliometric literature, this study provides a comprehensive picture of the direction of research development, collaboration patterns, and research theme dynamics, which can serve as a basis for further studies and the formulation of sustainable urban energy transition policies [20].

#### 4. CONCLUSION

This study presents a comprehensive mapping of scientific literature on renewable energy in the context of sustainable urban development through a bibliometric approach. The results of the analysis show that the topics of renewable energy, urban planning, and sustainability are increasingly integrated into global academic studies, with a significant increase in the number of publications over the past decade. In addition, keyword analysis, citation networks, and thematic maps indicate a shift in research focus from a purely technical approach to a more integrated discussion that links energy, environmental, and urban governance aspects.

This study also emphasizes the importance of collaboration in the research landscape, as reflected in the patterns of co-authorship and collaboration networks between researchers, institutions, and countries. Although this study does not directly evaluate the success of renewable energy implementation in the field, bibliometric findings show that a collaborative approach is increasingly seen as an important framework in urban renewable energy research. This pattern reflects the academic awareness that energy and urban challenges are complex and require the involvement of various disciplines and stakeholders.

However, it should be emphasized that the conclusions drawn in this study are based on patterns and trends in the literature, not on empirical measurements of policy impact or energy system performance. Given these limitations, the main contribution of this study lies in providing a structured overview of the direction of research development, key actors, collaboration patterns, and the evolution of research themes. These findings are expected to serve as a basis for further empirical and policy-oriented research, as well as to assist researchers and policymakers in formulating more informed strategies to support a sustainable urban energy transition.

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